



# Pilot Testing of Mercury Oxidation Catalysts for Upstream of Wet FGD Systems

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GREAT RIVER ENERGY<sup>R</sup>  
A Touchstone Energy<sup>®</sup> Cooperative



# Presentation Agenda

Project overview	Gary Blythe
EPRI perspective	Dick Rhudy
Background/prior research	Carl Richardson
Project plan	Gary Blythe
Schedule	Gary Blythe
Open issues	All

## Project Objective

Demonstrate at pilot scale the ability to use honeycomb catalysts to oxidize elemental mercury to a form that can be scrubbed in wet FGD systems, for periods of 14 months at each of two sites

# Project Team Members

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- URS Group
  - Design and construct pilot unit
  - Operate pilot unit, collect data
  - Conduct laboratory studies
  - Report results
- EPRI
  - Cash co-funding
  - In-kind cost sharing (Hg analyzer)
  - Project management

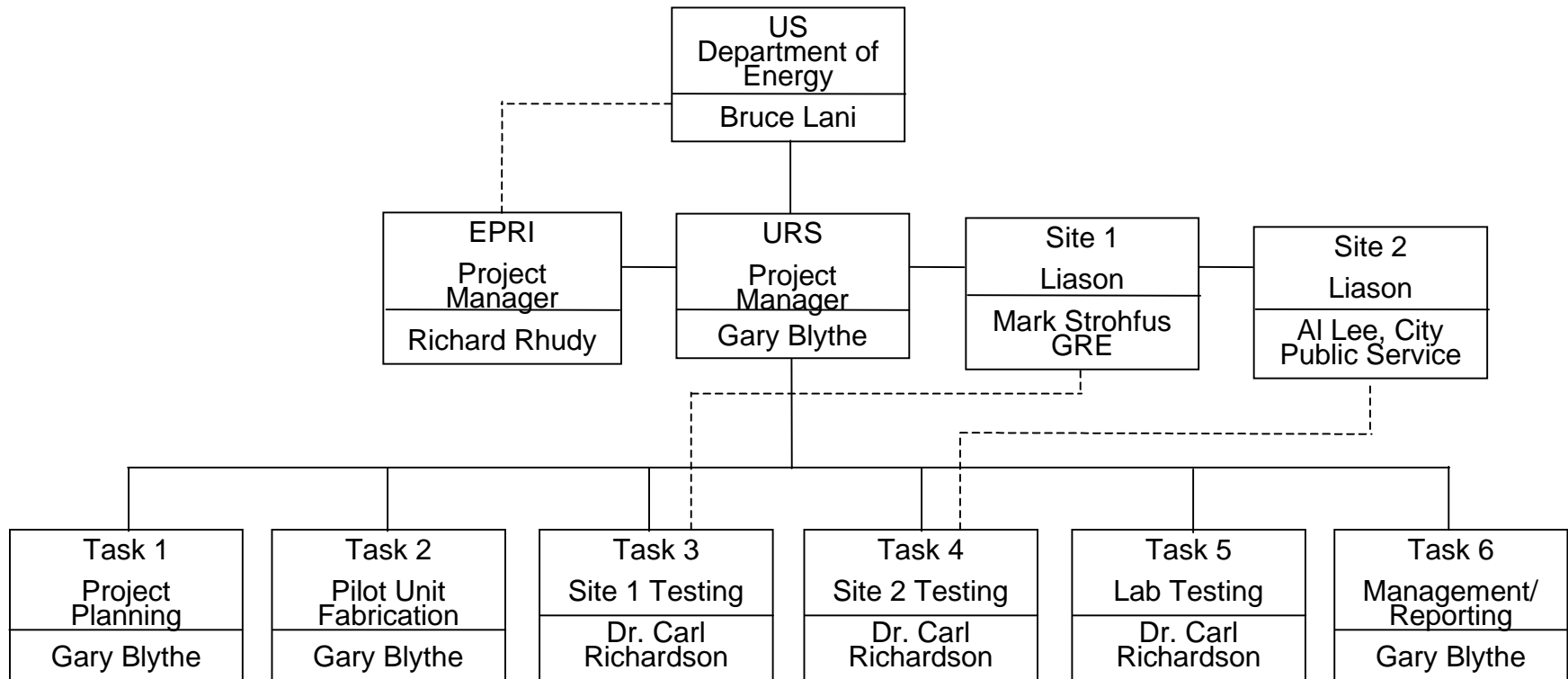


## Project Team Members (cont'd)

- Great River Energy
  - Host Site 1
  - In-kind cost sharing (pilot unit installation, operation support)
- City Public Service of San Antonio
  - Host Site 2
  - In-kind cost sharing (pilot unit installation, operation support)



# Project Organization



GREAT RIVER ENERGY<sup>®</sup>A Touchstone Energy<sup>®</sup> Cooperative

- Formed January 1999, consolidating Cooperative Power and United Power Association
- Based in Elk River, Minnesota
- Fourth largest G&T cooperative in the U.S.
- Second largest utility in Minnesota





- Serve 29 distribution cooperatives in Minnesota and Wisconsin
- Operations include 2,400-MW of generation
- Generation includes coal, lignite, gas, oil and RDF firing, wind power



- Founded in 1860, purchased by City of San Antonio in 1942
- Second largest municipal utility in the U.S.
- Serve City of San Antonio, Bexar County
- 2001 generating capacity of 5,027 MW (nuclear, coal, gas/oil)
- 27.6% of capacity is coal-fired (1400 MW)

# EPRI Perspective

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- Overview of EPRI Hg research programs
- Discussion of how this project fits into EPRI Hg plan



## EPRI Perspective

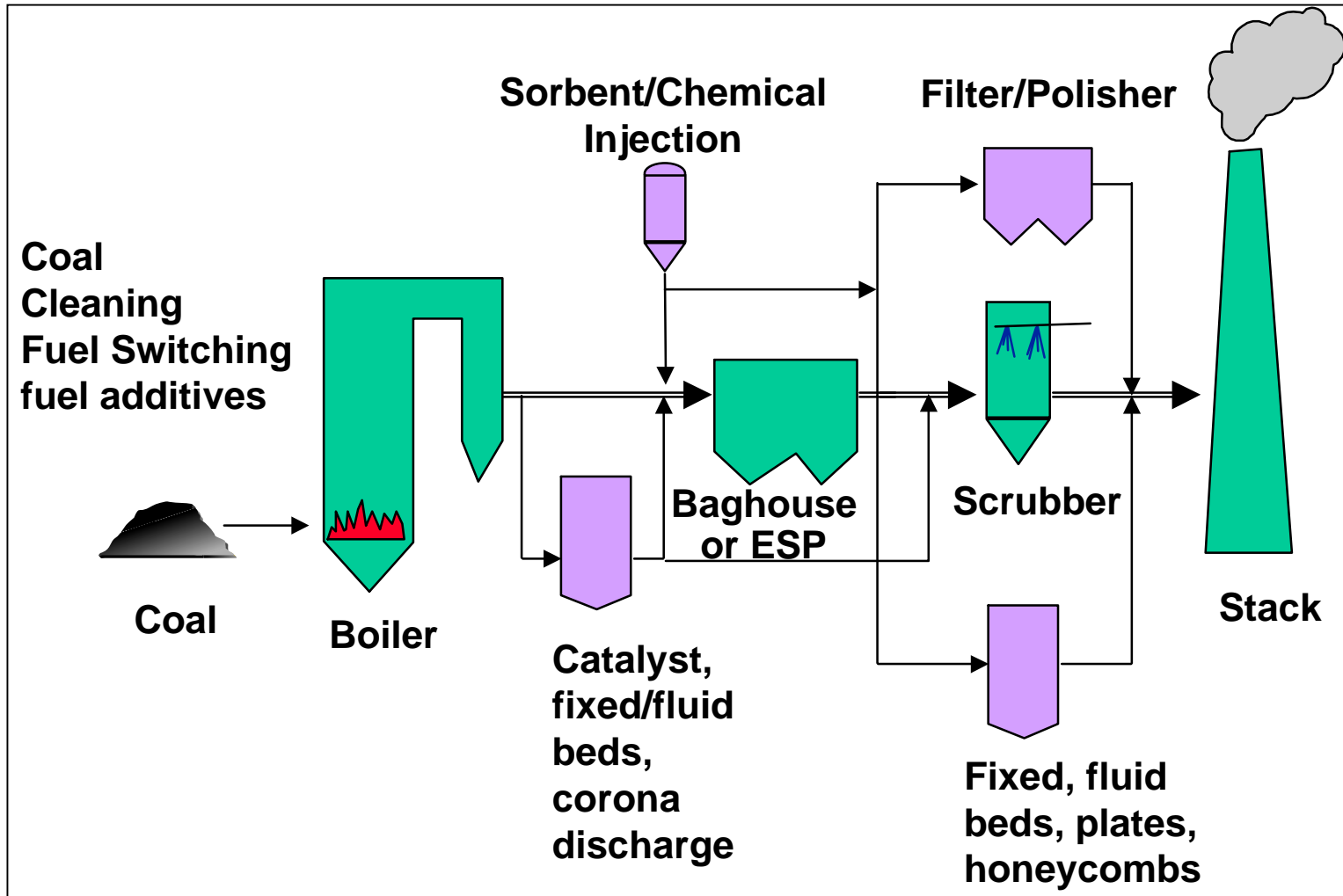
Issues Impacting Hg Control

- Hg is present mainly as vapor in flue gas at ppb levels
- Reliable methods to sample/measure/speciate Hg still under development
- Impact of Hg control on balance of power plant poorly understood
- Stability and disposition of waste products not clear
- Cost effectiveness needs to be established



# EPRI Perspective

## Mercury Control Options



# EPRI Perspective

## Method of Approach

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- Lab studies with simulated flue gas
- Field tests with small portable (1-10 acfm) and transportable (1000 to 4000 acfm) pilots
- Development of predictive models
- Full-scale demonstrations



## Cost-Effective Hg Control Candidates and Criteria

- Low lifetime cost
  - Capital vs. O&M (including waste, energy, plant life)
  - Impact on other power plant components
  - Retrofit ease
- Robust
  - Applicable to wide range of sites
  - Integration/compatibility with other pollutant control



## Future Plans

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- Evaluate balance of plant impacts and demonstrate sorbent injection at full-scale
- (DOE PRDA w/ADA-ES, other power plant hosts)
  - Add'l removal across ESP, impact on opacity
  - Ash use and disposal
  - Impact on baghouse performance
  - Actual sorbent usage
  - Novel sorbents
- Refine predictive model and costs
- Assess sorbent regeneration, mercury recovery



## Future Plans

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- Study fundamentals of flyash/LOI and other novel sorbent Hg (ultrafine high capacity, clay and zeolite based, in-situ formed)
- Field test concepts to convert elemental to oxidized mercury with catalyst and chemical additives
- Field proof-of-concept evaluation of selected novel, low-cost mercury control concepts (DOE and utility funding)



## Future Plans

- Evaluate multiple pollutant control potential and impacts
  - Measure particulate and trace air toxics (Pb, Ar, Se, Cr, Ni...)
  - Study potential for integration with  $\text{NO}_x/\text{SO}_x$ /Particulate control:
    - LNB, SCR/SNCR, reburn
    - Gas conditioning, humidification
    - Alkali injection
    - Wet ESP
    - Fabric development



# Project Background

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- Technology under development uses catalysts to oxidize elemental Hg in flue gas
- Oxidized mercury is scrubbed in wet FGD systems
- Initial concept development work by EPRI starting ~1993
- Further development as part of MegaPRDA beginning 1995



## MegaPRDA Project (95260)

- Phase I (1995-1997)
  - Lab investigation of catalyst activity
  - Short-term (~day-long) proof of concept tests at pilot scale with pulse-jet fabric filter reactor
  - Pilot-scale evaluation of Hg removal across FGD absorber, fate of absorbed Hg
  - Field testing of bench-scale reactor (5 l/min) for evaluating catalyst life



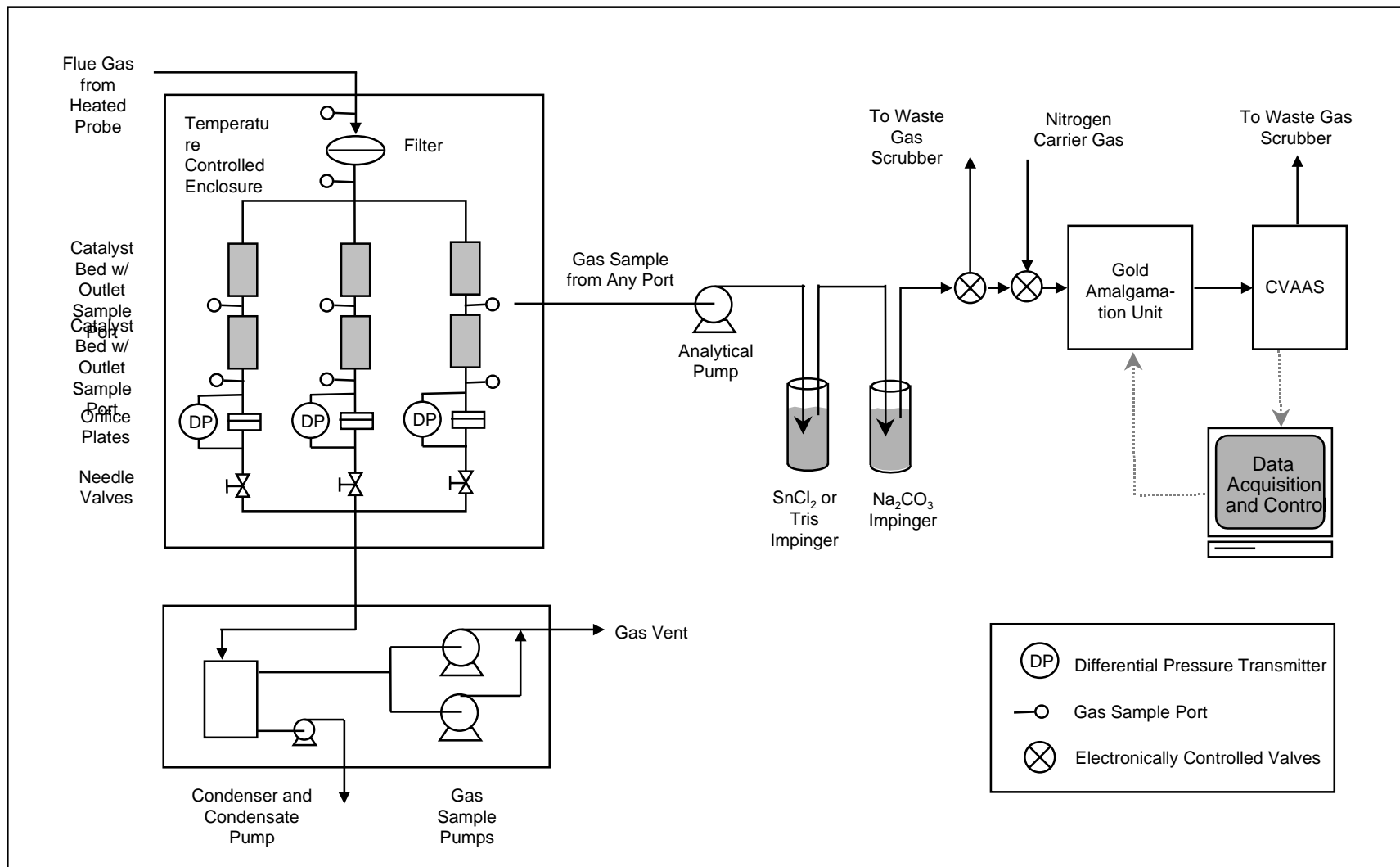
# MegaPRDA Project (95260)

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- Phase II (1998-2001)
  - Long-term (5-6 month) field testing of 5 l/min reactor for evaluating catalyst life
  - Testing at three coal-fired facilities
    - Texas lignite
    - Powder River Basin subbituminous
    - Eastern bituminous
  - Supporting laboratory studies
    - Screening candidate catalyst materials
    - Regeneration of spent catalysts



# Schematic of Field Test Unit



# Catalyst Types Tested

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- Carbons
  - Coal- or lignite-derived
  - Biomass- or waste material-derived
  - Impregnated (sulfur, iodine)
  - Carbon fibers
- Metal-Based Catalysts
  - Iron-based
  - Pd-based
  - SCR catalysts
- Fly Ash (various coals)

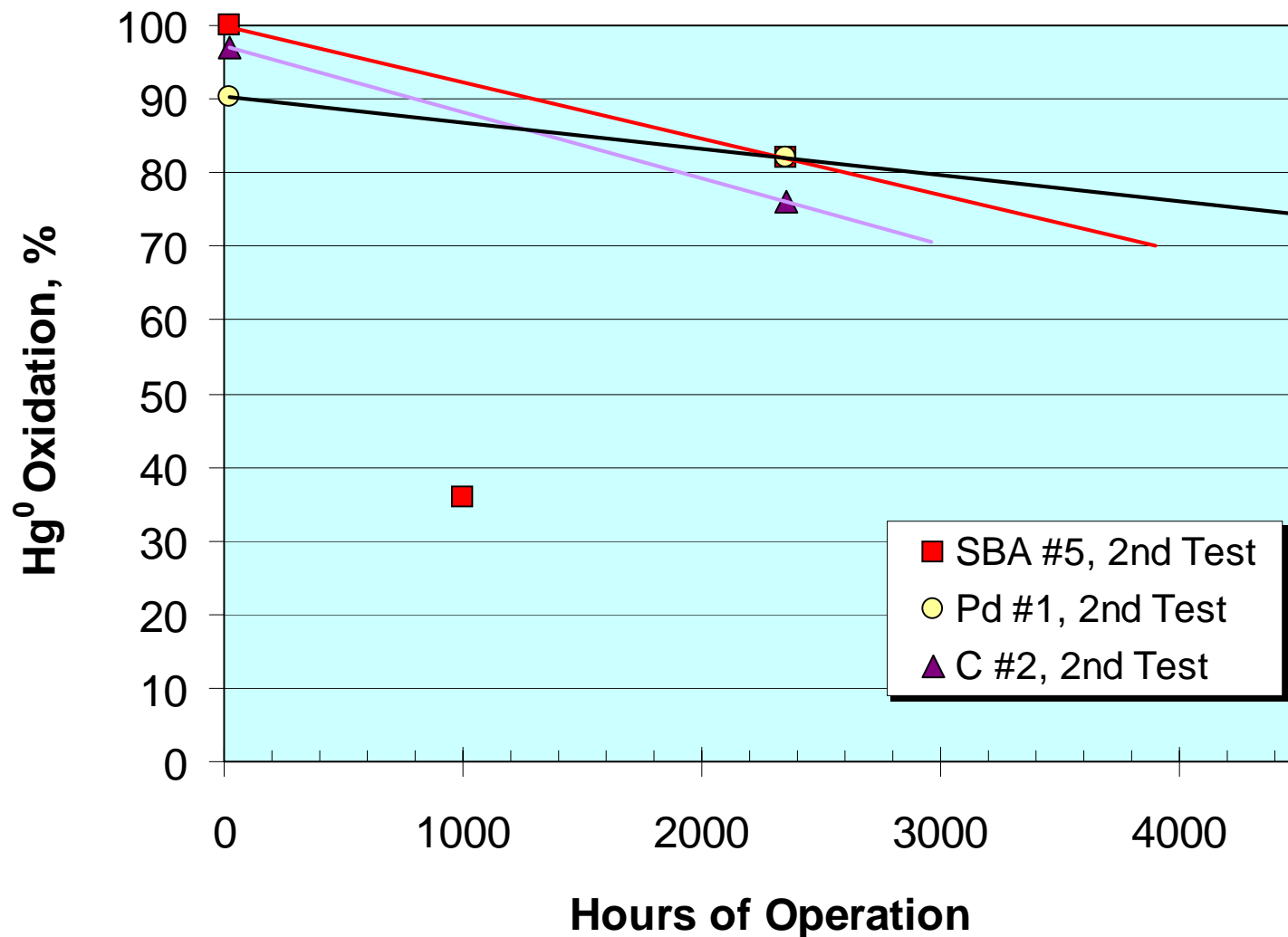


## Site 1 (Texas Lignite) Summary

- Saw high mercury oxidation percentages by several catalysts in short-term tests in lignite flue gas
- Catalyst deactivation observed within two months
- Second test with increased catalyst loading resulted in longer periods of activity



# Site 1 Mercury Oxidation Data - 2nd Test

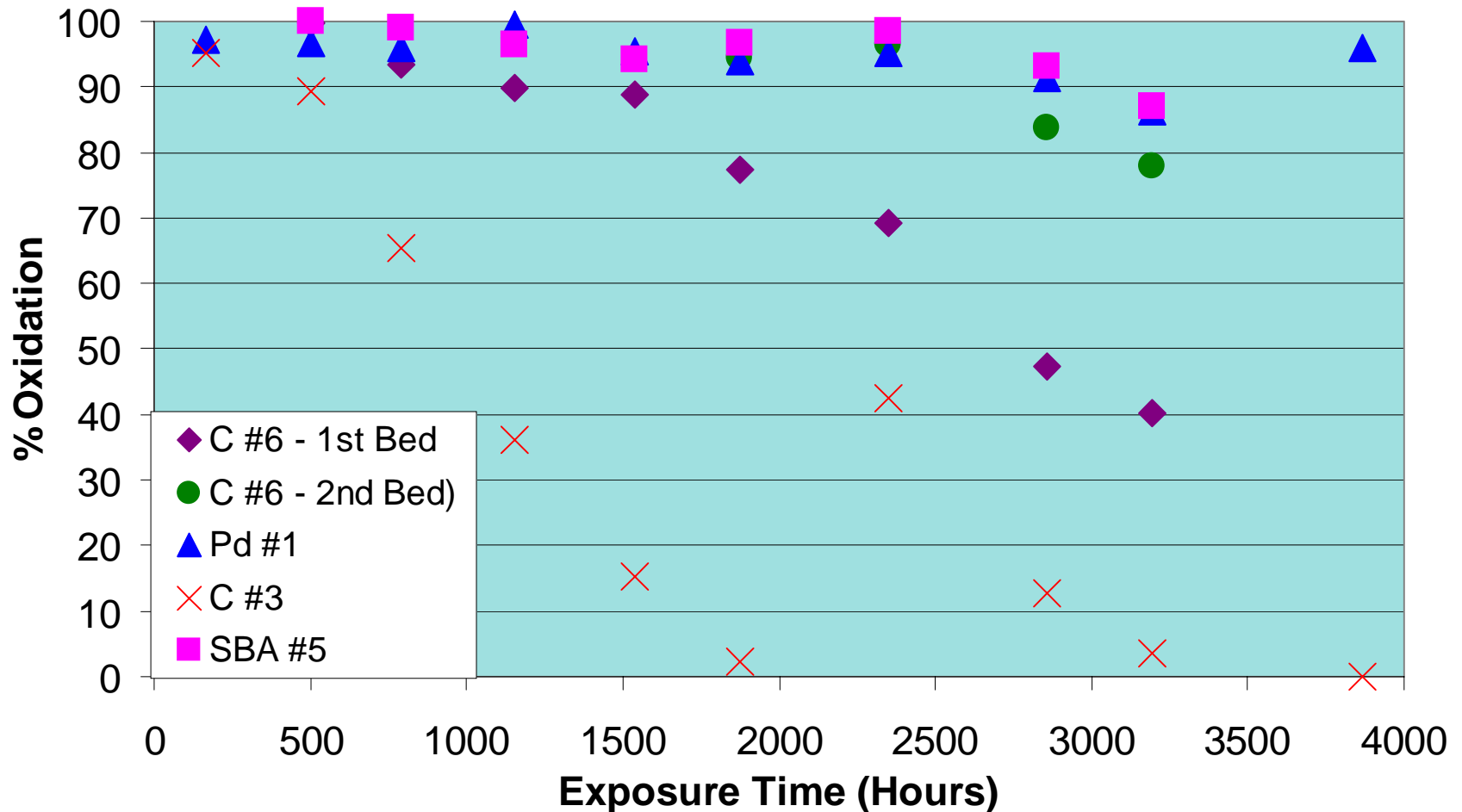


## Site 1 Summary (cont'd)

- Required catalyst quantities were higher than desired (large catalyst volume)
- Deactivated catalysts were easily regenerated ( $\text{CO}_2$  or  $\text{N}_2$  at  $700^\circ\text{F}$ )
- Sulfur and/or selenium appear to be involved in the deactivation process



# Site 2 (PRB) Catalyst Activity Results



# Ability to Regenerate Catalysts from Site 2

Catalyst	Hg <sup>0</sup> Oxidation (%)	
	End of Long Term Test	Regenerated in Air, 700°F
Carbon #3	0	0
Carbon #6 – 1 <sup>st</sup> Bed	40	94
Carbon #6 – 2 <sup>nd</sup> Bed	78	87



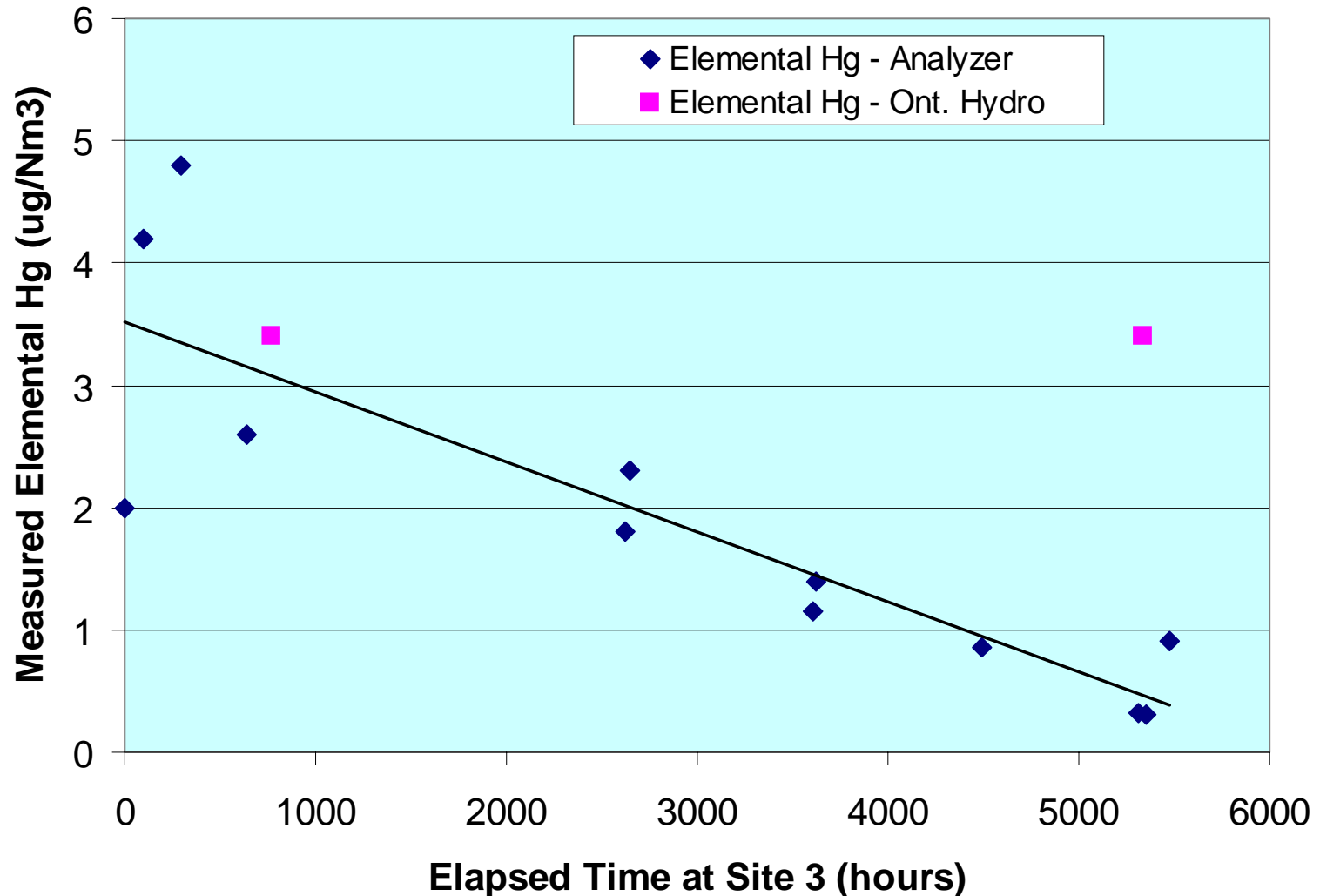
## Site 3 (Eastern Bit.) Summary

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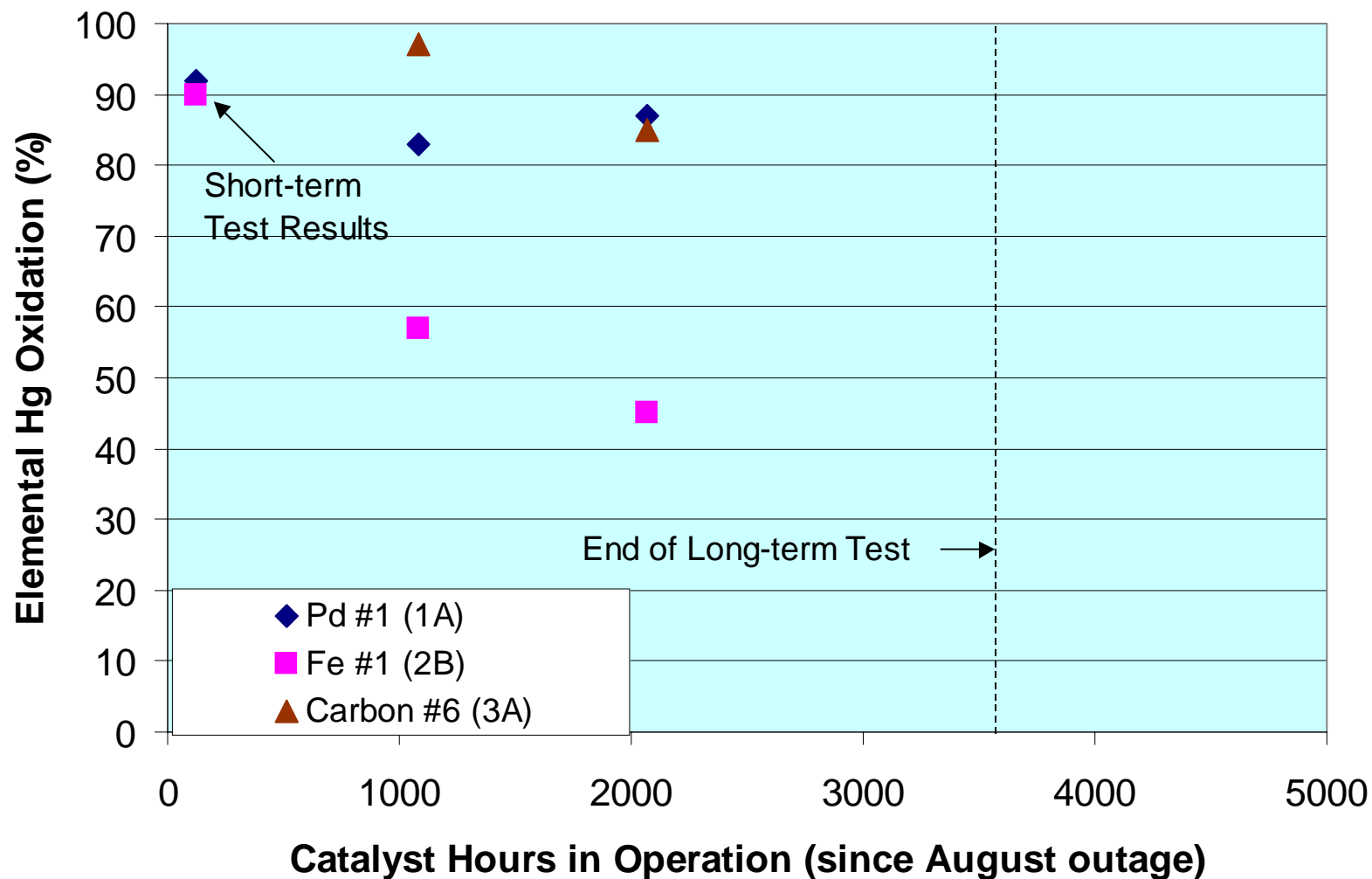
- Site 3 fires varied coal sources with a wide range of Hg content
- Site 3 fly ash appeared to adsorb and/or oxidize  $\text{Hg}^0$ , bias measured  $\text{Hg}^0$  in gas to long-term apparatus
- Made measurement of catalyst performance difficult



# Site 3 Inlet Elemental Hg Results



# Site 3 Catalyst Activity Results



# Ability to Regenerate Catalysts from Site 3 (Bituminous)

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- Pd #1 showed high activity after regeneration
- Activity of Fe #1 did not increase
- Carbon #6 was not regenerated (high activity as recovered from field)



# Commercial Catalyst Form Testing

- Focused on Pd #1, available in various forms from catalyst vendors
- Tested pellets and honeycombs at Site 2
- Honeycomb cell pitch same as clean-gas SCR
- Short-term honeycomb tests at Site 3



# Commercial Catalyst Form Test Results - Site 2 (PRB)

<b>Catalyst Form</b>	<b>Area Velocity (std ft/hr)</b>	<b>Oxidation of Hg<sup>0</sup> (%)</b>
Pellet	110	95
Pellet	210	97
Honeycomb	110	56
Honeycomb	190	51



# Commercial Catalyst Form - Predictive Model

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- Based on Hg mass transfer from flue gas to the catalyst surface limiting oxidation rate
- Predicts pellets should achieve higher oxidation than honeycomb at equal external surface area
- Field results for pellets were near model predictions; honeycomb results fell short of predictions

# Preliminary Economics for Catalyst-based Process - Assumptions

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- Pd #1 on honeycomb
- Base plant has a cold-side ESP followed by wet scrubber (no bypass), fires PRB coal
- Flue gas has  $10 \mu\text{g}/\text{Nm}^3$  total Hg, 25% oxidation
- 80% overall Hg removal requirement



# Preliminary Economics for Catalyst-based Process - Assumptions

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- 4-inch catalyst depth at ESP outlet to achieve 81%  $\text{Hg}^0$  oxidation
- 3-year catalyst life, no regeneration
- Compare costs to previous EPRI estimates for carbon injection with COHPAC fabric filter retrofit



# Preliminary Cost Estimate for 80% Total Hg Removal - \$1000

	<b>Catalyst/ Scrubber</b>	<b>Carbon Injection/ COHPAC</b>
Total Capital	\$1,950*	\$15,880
Levelized Capital	\$200*	\$1,620
Levelized O&M	\$2,130	\$2,540
Total Levelized Cost	\$2,330	\$4,160

\*Catalyst costs included in levelized O&M

# Current Project Plan (41185)

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- Task 1 - Project Planning
- Task 2 - Pilot Unit Design and Construction
- Task 3 - Testing at Site 1
- Task 4 - Testing at Site 2
- Task 5 - Laboratory Testing
- Task 6 - Management and Reporting



# Task 1 - Project Planning

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- Kick-off meeting
- Test plan
- Pilot unit design document
- Health and safety plan



## Task 2 - Pilot Unit Design and Construction

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- Complete detailed design
- Specify and procure instrumentation, valves, heat tracing
- Select and procure catalysts
- Select and manage a fabrication contractor
- Select and manage an insulation contractor
- Ship completed unit to GRE North Dakota plant



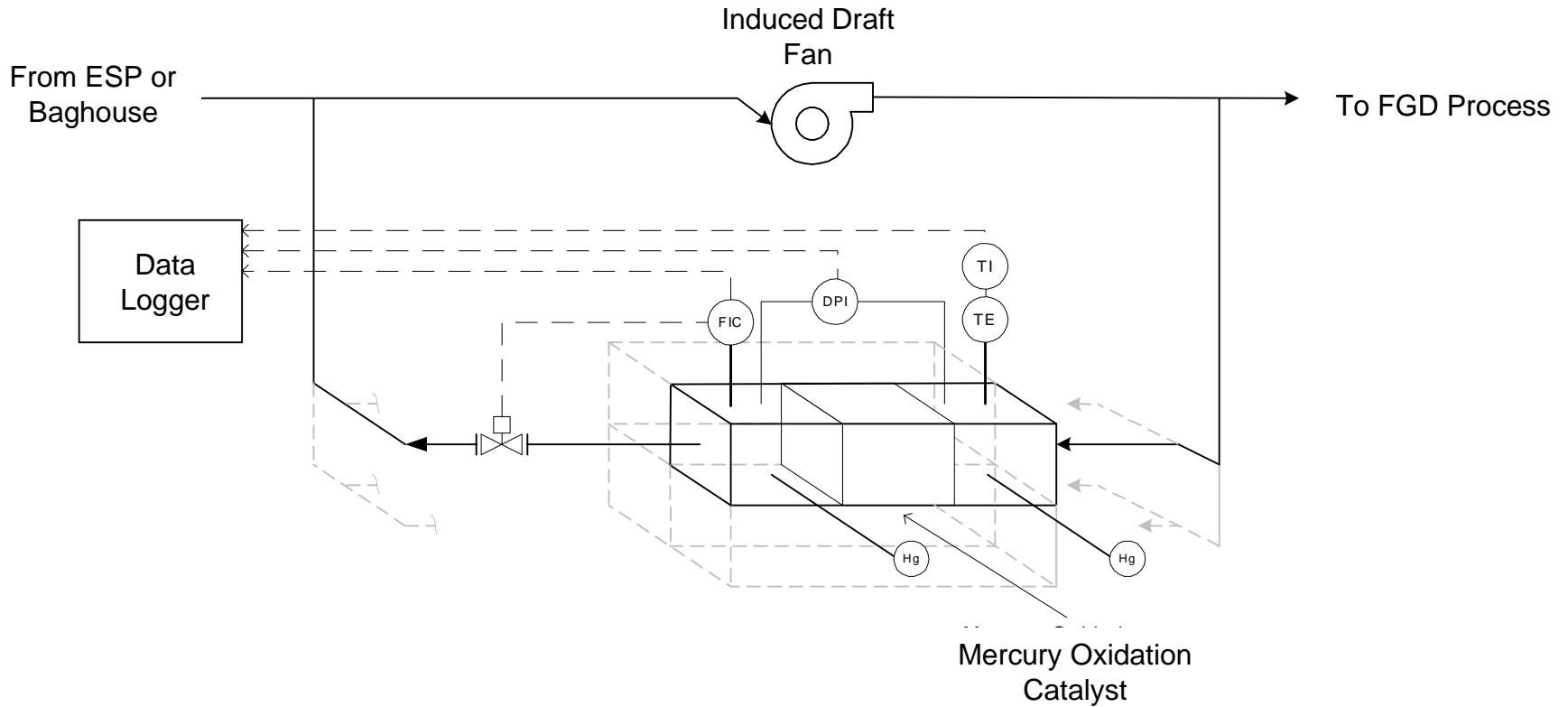
# Pilot Unit Design

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- Installs between particulate control and FGD on host plant
- Uses plant ID fan for motive force
- Will evaluate four catalysts in parallel
- Each catalyst chamber is up to 1 meter x 1 meter
- Flue gas flow rate is about 2000 acfm/chamber



# Simplified P&ID for Pilot Unit



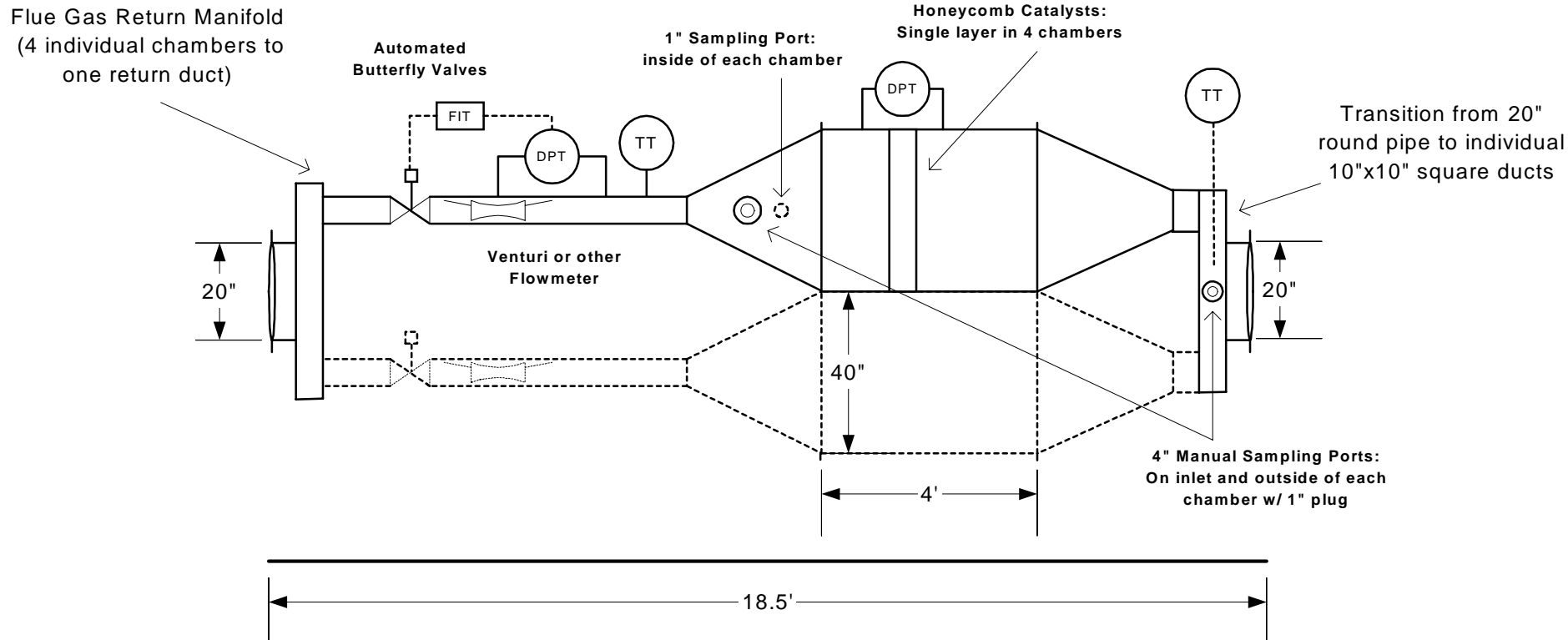
# Pilot Unit Instrumentation

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- For each catalyst chamber
  - Outlet temperature
  - Pressure drop across catalyst
  - Gauge pressure of chamber
  - Flue gas flow rate
- For pilot unit
  - EPRI semi-continuous Hg analyzer
  - Inlet temperature



# Pilot Unit Side Elevation



Top and Side views share the same dimensions except for supports and lifting lugs installed on the side view.

# Site 1 Candidate Catalysts

Catalyst Type	Supplier
Palladium on alumina	Prototech
SCR catalyst	Siemens, Haldor-Topsoe, others
Carbon based	ISGS, Corning
Fly-ash based	ISGS, Corning

## Task 3 - Long-term Testing at Site 1

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- Install and start-up pilot unit
- Install and place catalysts in service
- Operate pilot unit and catalysts up to 14 months
- Conduct intensive test periods (beginning, middle, and end of 14-month period)
- Conduct routine (~monthly) catalyst evaluations
- Remove catalysts and pilot unit, ship to San Antonio



# Great River Energy's Coal Creek Station

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- Two ND-lignite-fired units (550 net MW each)
- In-service dates 1979/1980
- Tangential boilers with low-NO<sub>x</sub> burners
- Located in Underwood, ND (near Bismarck)
- Lignite quality (nominal values)
  - 6300 Btu/lb
  - 0.7% S (2.2 lb/MM Btu)
  - 0.1 ppm Hg, 100 ppm Cl



# Coal Creek Station Emissions Controls

- ESP for particulate control (599 ft<sup>2</sup>/kacf SCA)
- ESP outlet Hg
  - 5-15 µg/Nm<sup>3</sup> (25-55% oxidized) in EPRI tests
  - ICR data showed 8 µg/Nm<sup>3</sup>
- Wet FGD
  - Alstom (was CE) spray towers (4 per unit)
  - 90% design SO<sub>2</sub> removal efficiency across modules
  - Lime reagent, natural oxidation
  - Flue gas bypass (~30%)

# Intensive Test Periods -

## Beginning and End of Long-term Period

- Flue gas Hg characterization/CEM validation by Ontario Hydro (ESP outlet, outlet 4 catalysts, FGD outlet)
- Determine SO<sub>2</sub>, NO oxidation across catalysts
- H<sub>2</sub>SO<sub>4</sub>, HCl, HF, metals at ESP out/pilot inlet
- Hg balance around ESP and FGD system
  - Hg in coal, fly ash, FGD liquor, byproduct solids
- Hg stability in FGD byproduct (air and water media)

# Intensive Test Periods - Middle of Long-term Period

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- CEM validation by Ontario Hydro (ESP outlet, outlet 4 catalysts)



## Routine (~Monthly) Testing

- Hg speciation at the inlet and outlet of each of 4 catalyst beds
- Use EPRI semi-continuous Hg analyzer
- Budgeted for one trip per month
- Possible on-site catalyst regeneration, if needed



## Task 4 - Long-term Testing at Site 2

- Install and start up pilot unit
- Install and start up catalysts
- Operate pilot unit and catalysts up to 14 months
- Conduct intensive test periods  
(3 - beginning, middle, and end)
- Conduct routine (monthly) catalyst evaluations
- Remove catalysts and pilot unit, ship to storage



# CPS' J.K. Spruce Plant

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- 546-MW generator nameplate rating
- Tangential-fired boiler
- In-service date 1992
- Fires PRB, some pet coke co-firing
- Coal quality
  - 8400 Btu/lb
  - 0.5% S (1.2 lb/MM Btu)
  - 0.1 ppm Hg, 100 ppm Cl



# Spruce Plant Emissions Controls

- Fabric filter for particulate control (2:1 A/C ratio)
- Wet FGD
  - Alstom (CE) spray towers (3 modules, 3 operate)
  - 70% overall SO<sub>2</sub> removal
  - Flue gas bypass (20-30%)
  - Limestone reagent, 100% natural oxidation
- Total Hg 9 µg/Nm<sup>3</sup> at stack (estimate 7-8 µg/Nm<sup>3</sup> elemental Hg at FF outlet)



## Task 5 - Laboratory Testing

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- Screen catalyst materials at simulated Site 1 and Site 2 conditions
- Investigate deactivation mechanisms
- Investigate regeneration conditions
- Possible laboratory regeneration of pilot catalysts, if needed



## Task 6 - Management and Reporting

- Routine monthly reporting
- Site 1 and Site 2 Topical Reports
- Final Report
- Technical papers as appropriate
- Project review meetings



# Project Schedule

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Submit Test Plan	12/15/01
Submit Pilot Unit Design Document	12/15/01
Ship completed Pilot Unit	3/1/02
Start up Pilot Unit at Site 1	4/1/02
Conduct Catalyst Space Velocity tests, Initial Gas Characterization	4/15/02
End Site 1 Long-term Test, Final Space Velocity, Gas Characterization Tests	5/15/03
Site 1 Review/Site 2 Planning Meeting	6/1/03